Cybernetics

Yu. Shreyder

8 September 1960

Following is the translation of an article by Yu. Shreyder in *Bol'shaya Meditsinskaya Entsiklopediya*, Vol. XII, Moscow, 1959, p. 749-766. Distributed by Office Of Technical Services U.S. Department Of Commerce Washington 25, D.C. as PRS: 5516 CSO: 4567-N.

C Y B E R N E T I C S (from the Greek kybernetike -- the art of control) is the science of the general laws governing control processes. The term Cybernetics was first used in its contemporary sense by the American scientist N. Wiener (1948). Proceeding from analysis of control processes in living organisms and technological devices, Wiener made it his task to study the general characteristics of control systems, since the processes which unfold in such systems possess important feat in common in spite of their highly diversified physical natures.

The most varied types of control systems are used in technology: these include systems for the control of artillery fire, for automatic control of the course of an aircraft (the automatic pilot), etc. With the appearance of electronic computers, a host of complex control-system designs based on the use of these machines has come into being. The Soviet Union's ``avtomashinist'' system, which controls the movement of an electric train, and a system for the control of aerial motion might be noted as examples. Of the control processes of the living organism which have been studied in recent years to a greater or lesser degree, we may mention the mechanism that control the transmission of hereditary characteristics from parents to the children, the mechanisms controlling blood pressure, body temperature, and the chemical composition of the tissue fluids, and many others. The most complex control processes are those related to the higher nervous activity of man and

the animals.

Cybernetics studies that which is common to all control processes with out replacing those sciences which are devoted to specific control systems (physiology, computer techniques, etc.). This makes it possible to penetrate deeper into the dynamics of the complex processes, describe them in exact terms, and effect simulation of the processes with the aid of systems of a simpler nature. If the control processes is described in exact quantitative terms, in the form of a finite mathematical scheme containing the description of the information used and the rules by which it is processed, it becomes possible to construct an artificial system -- a model -- which operates on the same rules. Experimentation with the latter permits us to study the peculiarities of the control process in question. In a number of important cases, simulation may be achieved successfully with the aid of so-called general-purpose computers; here it must be remembered that complete reproduction of all the properties of the process being simulated is impossible; it is important only that the model reflect the essential features of this process. This is what constitutes the limitation of the simulation method. However, the same factor is also responsible for the extensive prospects envisaged for the use of this method, which enables us to study real processes in different aspects, reproducing selected features.

Cybernetics studies processes of control as objective, determinate processes taking place in a physical environment. Furthermore the cybernetic approach makes it possible in many cases to detect concrete quantitative and qualitative relationships between various phenomena, thereby revealing the dialectic character of the dependence prevailing in Nature. The methodology of cybernetics

is still in the process of development. However, it can already be affirmed that this methodology is essentially profoundly materialistic and based en the dialectic unity of the various physical, chemical, and biological processes that occur in Nature, and that common laws are inherent in qualitatively diverse forms of motion. Cybernetics reveals one of these most important laws, which consists in the fact that in many cases (and perhaps always), the existence and evolution of highly-organized material forms is related to the presence of control processes possessing certain common properties.

The features common to control processes consist in the following. Each control system includes an object of control and a control apparatus. Receiving information on the state of the object and on external influences acting upon it, the latter converts it into into information which provides for the necessary action upon the object, thereby determining its correct behavior. Thus each control system consists of a controlling device (controlling organ), a controlled object, and channels along which information (a succession of physical signals which are stored, transmitted, and modified by the appropriate organs or devices) circulates.

The automation of the work of a sheet-rolling mill will serve as a graphic example of a technological control process: in this case a computer, receiving information on the incoming blank and the quality of the finished product, controls the velocity of rotation of the mill's rolls with the object of obtaining a rolled product of the highest quality. Due to such automation, it has become possible to reduce the tolerances in the thickness of the rolled sheet by a factor of 6.

The development of the conditioned reflex is also an illustration of of a complex specific control process.

In spite of the varied nature of the information in different control systems, general methods have been successfully worked out for their quantitative evaluation. Laws of a general nature also appear in the structure of the paths along which information circulate in various control systems. The concept of feedback, which is familiar to radio engineering and automatic control, also occupies an important position in cybernetics. In the example discussed above this concept has the following significance. In controlling the rolling mill, the control apparatus may receive information pertaining to the thickness of the rolled sheet. If this information indicates that the rolled product is of poor quality, the control apparatus will itself work out a set of conditions according to which the tension between the cages of the, mill will be changed.

In the above example, the control process makes use not only of information on the external factors, but also of information pertaining to the results of the object's performance of the specified operation. It is this second path of information transmission which is referred to as feedback. In this case, the feedback consists in the fact that the use of information on the quality of performance of part of the process makes it possible for the control apparatus to react more flexibly to a multitude of external factors (the type of metal, the temperature of the blank, etc.).

That to which we now refer as the feedback was first principle noted in physiology by I.M. Sechenov (q.v.), I.F. Tsion, and Ch. Sherrington. In the '30s, P.K. Anokhin (q.v.) called attention to the important role played by return afferentation in higher nervous activity, thereby indicating the vital significance of feedback

in the conditioned-reflex act: the biological value of the conditioned reflex is directly related to the possibility of its modification upon reception by the brain of information pertaining to the result of the reflex action.

Control systems may have many feedback paths (channels) along which information is transmitted on the quality of performance by the object of some part of the specified activity. *Negative* feedback appears when amplification of the control device's action on the object of control corresponds to an oppositely-directed action of the object the controlling organ. The presence of negative feedback is a requisite for the maintenance of any system in stable equilibrium. The physical significance of this effect consists in the following: an increase in the controlled quantity above a certain limit results in action on the part of the controlling organ to reduce this quantity.

The reduction of the controlled quantity produces an opposite reaction on the part of the controlling unit. *Positive* feedback consist in an effect in which information as to an increase in the controlled quantity, arriving at the controlling organ, stimulates it to a reaction which leads to a further increase in the controlled quantity.

In the act of urinatiom, for example, the pressure within the urinary bladder not only does not decline as it is evacuated, but even increases slightly toward the end of the process to assure complete evacuation. Indeed, a whole system of feedback loops may be detected in every real biological process -- just as in many technological control processes -- instead of a single feedback. In particular, detailed study of the physiology of urination would necessitate study of complex feedback

loops from the cortex of the cerebral hemispheres.

In cybernetics, general methods are developed for quantitative characterization of the information circulating in control systems. The quantitative evaluation of the information is based on the mathematical information theory worked out by C.E. Shannon, A.Ya. Khinchin, A.N. Kolmogorov and others. It is found that any information may be recorded (coded) in the form of a succession of ``yes'' and ``no'' signals usually in the arbitrary form of units and zeros. This means that the transmission of information may proceed as the transmission of a kind of ``questionnaire'' in each column of which ie recorded only the word ``yes'' or the word ``no''. The minimal number of columns in such a questionnaire that assures the transmission of the necessary information is a measure of the quantity of information. Thus the information is measured in terms of the number of ``yes' and ``no'' or ``zero'' and ``unity'' signals necessary for its transmission. Since the digits ``0'' and ``1'' are used to denote numbers in the so called binary system of numeration, the quantity of information is determined by the number of binary places necessary for its transmission.

The problem of methods of presenting, or coding, information is of great importance. The information may be recorded in the form of series of signals which assume only one of two values (e.g. ``zero'' and ``unity'', ``yes'' and ``no'', ``on'' and ``off''). Storage of information may be provided for by a complement of elementary cells capable of assuming two stable states. This property of information is widely used in electronic computing machines, where the information is stored in special memory devices built up from elementary cells. Such a cell may be formed for example, by a switch

which can be in either a closed or open position. This switch may be realized with the aid of an electron-tube or transistor circuit -- the so called trigger. Electron-beam tubes, tape recorders and ferrite cells are also used as storage devices. In the ``operative memory'' of a modern computer it is possible to store $4 \times 10^6$ zeros and units (or ``yes'' and ``no'' signals).

The human brain, which consists of approximately 1.4 to to 1.6×10^{10} neurons, can store a much larger quantity of information than the most highly perfected computing machine.

A second important characteristic of control systems is the method used to process the information. A peculiar property of control systems is their specificness, i.e. their capacity to react similarly to identical conditions in the external environment. Thus when all the experimental conditions are duplicated, a conditioned reflex developed by an animal may be repeated many times. This means that every control system has its own definite rules according to which information concerning the external environment and the behavior of the system itself is processed and the controlling response developed. A set of such information processing rules is called an *algorithm*. These rules may be recorded in symbolic form to produce a mathematical description of the algorithm.

Such rules can far from invariably be detected for complex biological processes, but cybernetics points the way to them in its ability to describe any control process. The search for algorithms in accordance with which control systems should operate plays an important role in the creation of technological control systems. In biology, description of control algorithms will permit the discovery of the properties of the biological

process in question.

It has been possible with the aid of electronic computers to achieve translation from one language to another (e.g., from English to Russian). This achievement came as a result of the determination and description of algorithms which make it possible not only to look up the words which have the same sense in the two languages, but also to determine the grammatical category of each work, analyze its context and select the most appropriate word from a group of synonyms, and then assemble all the words in the grammatical order peculiar to the language into which the text is being translated.

The fact that the control system functions according to algorithms which characterize its reactions under various external conditions guarantees stable behavior of this system under various types of disturbing influences from without. The continuous exchange of information with the environment id the maintenance of the controlled system in a definite state characterize the so called organization of the system, i.e. its stability with respect to external disturbances, which had previously been regarded as peculiar to living organisms. The presence of such organization in a system contradicts classical thermodynamics, and specifically the second law of thermodynamics which is sometimes called the principle of increasing entropy. The effect of this law, which characterizes the direction of thermodynamic processes consists, roughly speaking, in a statement to the effect that equalization of temperature and decay of complex structure (its approach to the level of orgnization of the surrounding medium) should everywhere. It follows from this that in the course of time, any closed system arrives at a state of thermal equilibrium characterized by identical temperatures of all its

component parts and the absence of organization.

In this sense, the existence of living organisms is in contradiction to the principle of increasing entropy, since living organisms are characterized by stability of organization and, in particular, by constancy of body temperature (in the warm-blooded forms). A certain degree of thermodynamic reversibility is observed in the living organism, i.e. it maintains its temperature and other physical parameters on a certain constant level other than the level of the surrounding medium. From the point of view of cybernetics, the reduction of the organism's entropy might be explained as due to the larger quantity of information used by the organism in numerous control processes; this is what makes the homeostatic properties of the organism possible. The use of information for control purposes apparently lie at the base of the functioning of systems with degrees of organization higher than those of the surrounding medium. Thus the cybernetic approach makes it possible to account for the existence of highly-organized systems in materialistic terms, without appeals to some sort of special extramaterial properties of the living organism.

It by no means follows from the above that we should conclude that the control processes in living and nonliving mechanisms are identical. We have already made reference to the important difference in the quantities of information used in living organisms and computing machirnes, which represent the most highly evolved creation of scientific-technical thought at the present time. However, the difference between the control processes in the living organism and even the most complex and up-to-date cybernetic devices is not only quantitative, but qualitative as well.

It is evident that the algorithms according to which living organisms function possess a number of complex properties which differ qualitatively from those known to technology at the present time. This qualitative uniqueness of the control processes in the living organism stems from the peculiarities of a new material substrate (living matter is formed of protein substances) and from its development, in the course of evolution, into an organic universe of highly organized beings.

An objection is frequently raised against the cybernetic approach in biology to the effect that cybernetics places an ``equals'' sign, so to speak, between the living and the nonliving and, in particular, ascribes to the computer qualities which are inherent only in the activity of living organisms. This objection is the result of the vulgarization of cybernetics and the attempt to present it as some sort of super-science which supplants all others. In actual fact, cybernetics studies only that aspect of biological phenomena related to the processes of control of functions which are in many respects analogous to the control processes studied in mathematics and technology. Here the question as to which laws of control processes are inherent only to living matter can be raised scientifically on the basis of study of the features common to living and nonliving mechanisms. This state of affairs is similar in many respects to one which has arisen in protein chemistry: only systematic study of the chemistry of the protein compounds makes it possible to reveal the specific properties of living matter.

Macro- and micro approaches are distinguished in the study of control systems. From the standpoint of the *macro approach*, the control system is somethdmg integral with a structure unknown in advance; only the

external behavior of this system is studied; from the nature of this we may judge of the complexity of the system, the volume of information used in it and the level of processing of the latter, i.e., the complexity of the algorithm. The *micro* approach proposes to study the elements of which the control system is composed, their inter-relationahips, the possibility of constructing a control system from these elements. From the standpoint of the micro approach, one of the differences between the control systems of biology and those of technology consists in the presentation of the energy source in the technological control systems as separate, independent components; it is for this reason that the problem of the energetic characteristics of the system plays an insignificant role in the planning of complex control systems in technology. In contrast to this, the sources of energy in biology are included in the cell itself, and their control is an essential and inseparable part of the control processes.

The problem of the reliability of the separate elements of control systems occupies an important position. The attainment of reliable breakdown-free operation of computing machines is one of the most complex problems of technology, since it is difficult to guarantee the simultaneous operation, without malfunctioning, of the thousands of electron tubes used in every machine. In living organisms, to which high functional reliability is inherent, there are far larger numbers of structural units (cells). It is clear that special mechanisms have been developed in living organisms to provide for such reliability. Therefore this question as to how the organism really achieves such perfect performance is of particular interest. Improvement in the reliability of a system is attained by two methods in technology:

duplication in time or in space. In other words, in order to obtain a reliable answer in the solution of a problem, this solution must either be repeated more than once or the problem solved on several similar devices. Highly reliable operation of the whole may be obtained by such duplication even when the separate elements are relatively unreliable.

Something similar -- if not always in mechanism, then at least phenomenologically -- apparently occurs in living organisms as well. Thus, experiments on the development by rats of a habit consisting in transversal of a maze with the purpose of reaching bait are quite familiar. Upon removal of various areas of the cerebral cortex from the animals, the developed habit first vanishes but ie later restored; here the chances that the habit can be restored depends basically on the size of the extirpated area. It follows from this that due to the exceptionally high adapabi1ity of the nerve centers, they are capable, under certain conditions (involving signals of a new type) of ``relearning'' and thus supplanting one another through the formation of new compensating mechanisms and paths of communication. It appears that such interchangeability is also achieved in other biological control mechanisms as well.

The application of cybernetics in a number of biological and medical fields has already enabled us to achieve certain practically useful results or shown promise of such results in the future.

A number of projects devoted to simulation of the biological activity of the heart have recently been reported. Investigations of the laws governing the heartbeat have resulted in a description of the mechanism which controls the contraction of the muscles of the heart. This has made it possible to create analogues

capable of simulating the bioelectrical processes which take place in the heart in normal and pathological states. By inducing various disturbances in the operation of this electronic analogue, it has been found possible to reproduce artificially the electrocardiograms of diseased hearts suffering from various forms of disorder. This makes it possible to guide the physician to an opinion as to which types of heart-activity disturbance may correspond to a given clinical picture, i.e., facilitates his arrival at a diagnosis.

In this connection, the possibility has been considered in the literature of constructing an electronic computer which assists in the diagnosis of illness on the basis of a number of symptoms obtained as a result of medical examination and analyses. Such a diagnostic machine should store information on the characteristics of various illnesses with the symptoms of each of them. After coded information on the combination of symptoms of illness exhibited by a given patient has been fed into the machine, the computer would perform a large number of comparisons and select one or more illnesses (indicating the degree of probability of each of them) which come closer to corresponding to the given set of symptoms. The quantity of information necessary for logical analysis of the data of medical examination and laboratory tests is within the limits of capability of modern computing machines.

One of the most important directions taken by cybernetic applications in medicine is the development of working prosthetics. The concept of working prosthetics consists in the formation of new chains of transmission of information to replace chains used in the control mechanism of an extremity before its amputation. The motion of an arm or a leg is usually controlled on

the basis of information obtained from proprioceptors, which circulates along a feedback channel. When the activity of these receptors is disrupted, feedback is achieved with the aid of visual information. In *tabes dorsalis*, for example, an individual is incapable of performing adjusting movements or retaining a vertical position with his eyes closed. This is due to the absence of compensating transmission from the proprioceptors.

N. A. Bernshteyn (q.v.) and, soon afterward, N. Wiener advanced the idea of designing prosthetics which made it possible to form new feedback loops by the use of information arriving at the receptors in the stump. After appropriate training, the necessary information transfer circuits form in the patient's nervous system and conditioned reflex motions which permit proper control of the prosthetic are developed. In this case, the motion of the prosthetic is produced by the mechanical exertions of the stump, as usual.

A new method of working prosthesis in which the prosthetic is controlled by means of the biocurrents has been developed in the Soviet Union (V. S. Gurfinkel t et al.). A working experimental prosthetic wrist (``mechanical hand'') has been cntstructed on this principle. Sensitive pickups which register the biocurrents of the nerve ends of the arm transmit the appropriate information to a motor which sets the prosthetic into motion with sufficient practice, a man can learn to produce the necessary movements with his prosthetic.

In this case the role of the feedback loop is taken by the channel along which visual information is received. Control of prosthetics by this principle is highly promising since the biocurrents can be used to transmit a large quantity of information: the sensors can react to the voltage and frequency values of the biocurrents

and their other parameters. The principle of biocurrent control may have great prospects in the remote control of manipulators of various types, e.g., in working with radioactive materials, etc. An important problem of prosthetics is the functional storation of sensory organs and, in particular the creation of apparatus with which the blind can read printed texts. Such a device could translate printed letters into letters of the Braille alphabet, which the blind individual would perceive by touch, into a conventional sound code and later even into actual audible speech. The leading process is based on counting the number of intersections of a reading beam with the contour of the letter. In running over the individual letters, the reading beam crosses their contours at different instants, and also different numbers of times.

Each intersection with the contour is registered by a photoelectric cell and converted into an electrical pulse. The basic difficulty in the construction of such an apparatus consists in the need for adaptability to type faces which differ in size and design. The apparatus must determine what is common to the various forms in which a given letter is written -- i.e., that which is common to sequences of electrical pulses arriving from printed in different styles. For this purpose the beam should scan only the areas on which the individual letters are printed, i.e., it should first automatically determine the size of the letter.

The circuitry of such an apparatus was worked out in 1947 by W. MacCulloch. The device received signals from photoelectric cells which sensed a reflected beam of light scanning an entire text in sequence, letter after letter. The resulting sequences of electrical pulses were converted and approximated to a certain.

standard form which did not depend on style. This has led a number of physiologists to the concept of such a mechanism in the visual region of the cerebral cortex, since a human, on receiving various light signals which depend on the type face or handwriting in which the communication is couched, senses them in the process of visual perception as equivalent ideograms.

This problem is also important for the automatic input of printed matter for translation from a foreign language and various documents for financial accounting into electronic computers. The even more difficult problem of automatic reading of texts written by hand with special magnetic inks on special forms has already been solved in principle. Here it is important only that the letters and digits occupy definite positions with reference to the lines marked on the form. The introduction of information into computers will be significantly simplified with the final solution of this problem, and it will also become possible for the blind to read not only printed texts but handwritten manuscript as well. Study of the information potential of the various receptors is discovering much that is promising. Thus, for example, it is known that sight is ranked first among the internal receptors in volume of information sensed, touch second, hearing third and thereafter smell and taste. Studies being made in the Soviet Union of the information characteristics of color vision is of direct significance for the proper calculation of the transmission capacities of communications channels for color television.

Research into the control processes involved in the transmission of hereditary characteristics from parents to their offspring and the development of the new organism is important. According to the chromosome

theory of *heredity* (q.v.) the chromosome complement of the zygote contains inheritance information ``recorded'' in the form of a chemical code determined by the chemical structure of DNA (see Deoxyribonucleic Acid) molecules. The presence of definite information at a given locus on the chromosome corresponds to the presence of one of four possible radicals at a definite point on the DNA molecule. This information is subsequently receded into formation that determines the development of the cell. A theory exists according to which the DNA molecules serve as catalysts in the synthesis of ribonucleic acid (RNA) molecules, thereby determining the structure of latter's radicals. The RNA molecules in turn emerge as catalysts in the synthesis of protein molecules. Reproduction of the information ``recorded'' in the chromosomes takes place during cell division. Great progress has been made in recent years in clarifying the physical nature of the carriers of inheritance information.

According to preliminary estimates by certain authors, the volume of information in the chromosome is extremely large: it would be equivalent to 10^5 binary places. Information-transmittal processes related to the development of the organism's various cellshave not been studied as thoroughly. It has been possible in experiments with amoebas to establish the existence of feedback paths between the nucleus and the protoplasm; these paths play a decisive role in establishing the tempo of the amoeba's division, i.e. the number of divisions it undergoes per unit time. The opinion has been expressed in the literature that the formation of malignant tumors is d.u.e to a disturbance of the processes controlling the exchange of materials in the cells; as more factual material accumulates the cybernetic

approach may be found promising even in studies of disturbances of the normal growth of cells.

Much may be expected of the use of various types of control devices in surgery, since the surgeon must obtain the most complete information possible on the condition of the patient during the operation. Operating rooms are already equipped with complicated apparatus which makes it possible to follow the condition of the patient. The number of such apparatuses and instruments will increase still further in the future., and special installations will be required to interpret electrocardiograms, electroencephalograms, graphic or digital characteristics of respiration, blood pressure, temperature, etc. Automatic processing of this extensive body of information will enable the surgeon to arrive at the necessary decisions quickly. The idea of using automatic devices to control artificial respiration must be recognised as worthwhile (particularly in gas anaesthesia, where a special computer can be used to maintain a specified depth of narcosis). Control of the devices that meter the particular gaseous mixture in to the lungs may be accomplished by using the appropriate devices to process data on the partial pressure of the carbon dioxide in the expired and aveolar air or on bio-currents arising in the central nervous system. Here the basic difficulty consists in proper interpretation of the information obtained and the the finding of control algorithms for the operation of the apparatus applying the artificial respiration.

As we have already noted, the processes of higher nervous activity in men are among the most complicated control processes. A number of papers have recently appeared in which the authors regard psychic derangements as disturbances of certain control processes. Thus for example. W. Ross Ashby makes an attempt to ascertain

which types of control-process disturbance correspond to various kinds of psychic illness. Psychic derangements are usually functional in nature, and are frequently not accompanied by detectable logical changes in the cerebral cortex. Functional disorders of various kinds are also observed in the operation of complex computing machines -- particularly in the case of defects in the circulation of information -- due to the loss of individual pulses, disturbance of the synchronization of the various units, etc. This analogy led Ashby to a number of hypotheses pertaining to the mechanism of the functional disorders governing the symptoms of certain psychic illnesses. It is to be noted that hypotheses of this kind require serious attempts at confirmation. At the present time, we can speak only of first steps in this direction, from which we should not expect immediate results which can be used in the clinic.

Study of the processes of higher nervous activity presents one of the most difficult problems of physiology. The conditioned reflex doctrine created by I.P. Pavlov has served as a basis for objective investigation of these processes. Pavlov himself wrote of the inevitability of recourse to mathematical analysis of the laws governing conditioned-reflex activity in the future development of the science: ``Each animate organism is a complex individualized system whose internal forces maintain equilibrium with the external forces of the environment every moment of its existence as such … A time is coming however remote it may be, when mathematical analysis proceeding from natural-scientific analysis will embrace all these equilibiations with grand formulas of equations, including in them, finally, even itself.''[1] The mathematical apparatus needed for this in the light of present development of science consists in description

[1] I.P. Pavlov, *Dvafistailetnyy opyt ob``yektivnogo izucheniya vysshey nervnoy deyatel 'nosti* (Twenty years' experience in the study of higher n nervous activity), Moscow/Leningradt 1938, p. 123

of the algorithms lying at the roots of the processes of higher nervous activity.

Reports already exist which furnish quantitative descriptions of the laws observed in the development of conditioned reflexes. Thus it has been found possible to estimate the quantity of information arriving from new stimuli and use an animal by attachment to previously-formed chain of conditioned reflexes. Specifically it has been established that animals rely in each experiment not only on the information which arises. in the particular experiment, but also on their previous experience and on their inborn instincts.

There exist many papers devoted to the so-called mathematical theory of learning. On the basis of certain hypotheses pertaining to the dynamics of habit formation, the authors construct a mathematical theory of learning based on the assumption that an animal may carry out different activities with different probabilities under the conditions of an experiment. When a definite habit has been develops in the animal, the probability of one of the possible courses of action is close to unity, while the probability of the remaining activities is close to zero. Thus single definite action will practically always be performed. The process of habit formation consists precisely in the increasing probability of a single defined action from experiment to experiment until it approaches unity.

The mathematical theory of learning which enables us to describe the dynamics of habit formation, is a phenomenological theory, i.e., it does not propose to analyze the nature of the internal linkages which arise in the process in the cerebral cortex. In spite of this, the above theory has merit in that it develops a certain quantitative method which describes the process

of habit formation. This theory has been successfully applied to description of the behavior of an animal under varying external conditions; it has made it possible to evaluate the complexity of the mechanisms which regulate the development of various habits.

Simulation of isolated acts of behavior inherent to animals with the aid of mechanisms is of definite interest. We know of attempts to create working models which reproduce manifestations of living creatures under various external conditions. Thus ``bug'' and ``moth'' models which mimic elementary tropisms have been constructed. The ``bug'' model moved in the direction away from a light source, and the ``moth'' model moved toward it. Models referred to as ``turtles'' could circumvent obstacles as they moved; with these, it was possible to obtain phenomena simulating the simplest conditioned reflexes by combining a whistle with the obstacle; the ``turtle'' would stop at a single blast on the whistle. A ``mouse'' model created by C.E. Shanon has also been reported; this ``learned'' to find the correct path through a maze after one test. This model indicates that a whole series of simple behavioral acts may be reproduced by mechanisms (but, of course, only purely phenomenologically). Simulation of other types has been accomplished apart from working models. Ashby developed a model of the so-called homeostat.

This model has the ability to ``find'' a stable condition when various external stimuli act upon it. Ashby's homeostat consists of several, sections linked by a complex system of feedback paths. Random disturbances acting on the homeostat throw it out of its equilibrium condition. Thereupon the homeostat ``searches'' for a new stable conditions examining a large number of different states in the process.

The functioning principle of the homeostat is similar to the principle by which living organisms secure stable states. However, comparison of the functional principles of the homeostat and the brain, indicates that much more complex algorithms lie at the basis of the brain's operation. This becomes evident in the fact that the homeostat passes through a very large number of intermediate states before finding a new stable state, and cannot make use of its ``past experience'' (the reproducible nature of the disturbing influences) to shorten the time spent in the search. In contrast to this, animals generally use the past experience related to the formation of their complex habits.

A process which simulates the development of a conditioned reflex has been realized with electronic computers. First the machine printed digits in an arbitrary sequence, and then ``learned'' to isolate one of them if a ``consent'' signal was fed to the machine on each appearance of this digit. After delivery of this signal was stopped, i.e., ``the reflex was not sustained'', the machine again began to print all digits at random. The external features of the process of conditioned-reflex development are reproduced nicely in this form of simulation. Study of such models permits deeper understanding of the various aspects of this process, the linkages which are probably established in it, and the nature of the information used. It is important in simulation that it the be perfectly clear which properties of the reflex activity are not reflected by the model. This indicates at once which aspects of the reflex activity have not been sufficiently studied. In particular, attempt to simulate the so-called protective inhibition encounter great difficulty.

Analysis of the behavior of living organisms indicate

that the algorithms at the basis of their behavior are immeasurably more complex than the algorithms built into the simplest models. A live mouse, for example, solves the problem of exploration of maze by a method totally different from that employed in the mechanical mouse model. Not possessing specific adaptations to a given specific problem, as is the case with the mechanical mouse, the living mouse uses a much larger volume of information on the maze; as a result, its behavior is incomparably more plastic and, in the final analysis, more efficient. Experiments on live mice and rats have indicated, for one thing, that the process of habit formation may be provisionally divided into three stages. The first stage is one of selection of the information needed for formation of the habit; this stage is characterised by random exploration. The second stage sees the selected information used in the process of habit formation; this part is characterised by purposive exploration with systematic reduction of the number of errors in each test. The third stage is the formation of the habit and the solution of the problem of search with a minimal number of errors which depends on the individual properties of the experimental animal involved.

In the formation of conditioned reflex chains consisting in the development by the animal of a sequence of actions related to definite conditioned stimuli, it becomes evident that the rat or mouse does not mechanically try all possible combinations of the action as would an animal not possessing experience to begin with. On the contrary, the animal uses its previous experience to the maximum: it employs finished reflex chains which were formed under other conditions.

Many experiments have shown the development of reflex

chains in which the use of a preceding link is the conditioned stimulus for the subsequent link. By progressive cultivation of such links in the animal, we develop a sequence of acts culminating in an unconditioned sustaining stimulus. Here it is found that if certain links were developed earlier for other defenses, they are very quickly restored and used as finished component parts in the newly-developed sequence of reflexes. Thus, for example, in the development of a chain of reflexes related to nutrition, the animal uses previoulsy completed reflex chains developed for the removal of unpleasant stimuli. Maximum utilisation of previous experience and the presenceof various complex associations are characteristic of the algorithms of higher nervous activity in animals and man.

The creation of electronic computers which ``remember'' a large volume of information and perform tens and hundreds of thousands of arithmetical operations per second has enabled us to simulate various algorithms, including some that were hitherto regarded as the exclusive property of the human brain. Thus it has been possible to effect machine translation from one language into another. Admittedly, this method is suitable only for the translation of specialised texts in which the large batteries of words and nuances found in belle letters are not required. Nevertheless, the creation of automatic-translation techniques has provided testimony to the considerable progress made in the study of complex algorithms.

Attempts to apply computers for the reproduction of other processes formerly considered to be doubly creative and conferred only upon man are described in the literature. Thus, the ``Calliope'' computer constructed by French scientists writes ``literary

compositions'' consisting of phrases related by associations. True, these ``compositions'' in prose and verse have no artistic value whatsoever in view of their lack of common sense. Attempts to use computing machines to create musical compositions are even more interesting. Electronic machines have been made to orchestrate compositions according to definite rules. The machine finishes its orchestration of a simple composition in a few minutes, while a specialist requires three days for the same job. It has also been found possible to use the machine to compose melodies. For this purpose the computer selects a random sequence of notes, taking into account the probability of the use of various sound combinations in a musical composition.

In this process, the machine selects each time only those notes which conform to definite rules. These rules were derived as a result of analysis of about one hundred popular songs? their structure was not highly varied and such random selection, when restricted according to certain rules, can produce a large number of melodies in no way worse than the initial samples.

Attempts to automate such processes invariably necessitate elaboration or exact description of algorithms; this constitutes a much more difficult problem than the application of the computers for their realization. In those cases in which the control algorithm can be described mathematically, it can usually be carried out by a machine as well. Thus work toward the creation of algorithms for automatic translation has led to emergence of a new branch of science--mathematical linguistics, which is already making a noteworthy contribution to contemporary language science.

It is difficult to say at the present time which functions the machine can perform and which it cannot.

The potential of the human being is immeasurably larger that that of even the most accomplished of contemporary computing machines. It can only be assumed that as man comes to understand the complex algorithms underlying the biological processes, possibilities will appear for the simulation of these algorithms, with the aid of computers.

The rapid tempo of the development of the technical means of cybernetics -- the phenomenal growth of the production of semi-condoctor devices, miniature radio components, the creation of elements that operate on new physical principles -- all this is making cybernetic apparatus cheaper, easier to handle, and more reliable, and with the further development of science and technology will contribute to the penetration of these machines into medicine and biology. It remains only to be stressed that the computing machine can be used efficiently where high operating speed and the a analysis of large volumes of information are required. Man, however, still possesses a tremendous advantage over the machine in the solution of those control problems in which the vital experience of man, enriched by the scientific and social experience of humanity, plays a major role.

One of the noteworthy properties of Cybernetics consists in the possibility of studying the problems of biology and technology from a single quantitative standpoint; this makes it possible, on the one hand, to perfect technology by transferring a number of functions formerly peculiar to man to the machine for execution, and on the other to study the properties of life by creating models which simulate certain properties of living organisms. This opens the possibility of converting biology and the cognate branches of science -- one of which an is medicine -- into an

exact science. A Scientific Council on Cybernetics, composed of representatives of the various sciences, including biology and medicine, was recently created by the Presidium of the Academy of Sciences of the USSR. (See also *Physiology*)

Bibliography

Avtomaty (Automatic devices), edited by C.E. Shannon and J. McCarthy; translated from English, Moscow, 1956.

Anokhin, P.K., *Osobennost afferentnogo apparata uslo nogo refleksa i ikh znacheniye dlya psikhologli (The properties of the conditioned-reflex afferent apparatus and their significance for psychology)*, Vopr. psikhol. (Problems of Psych.), No. 6, p. 16, 1955 and *Fisiologiya i kibernetika (Physiology and cybernetics).* Vopr. filosofii (Problems of philosophy), No. 4, page 142 1957.

Wiener, N., *Kibernetika (Cybernetics)*, translated from English, Moscow, 1958, and *Kibernetika i obehchestvo (Cybernetics and society)*, translated from English, Moscow, 1958.

Vishnevskiy, A.A., Shik, L.L., and Khodorov, B.I., *Kibernetika v khirurgii (Cybernetics in surgery)*, Eksperimetal khirurgiya (Experimental surgery), No. 1, p. 6, 1959.

Gamov, G., Rich, A., and Ikas, M., *Problema peredachi informatsii ot nukleinovykh kislot k belkam (The problem of information transmittal from nucleic acids to proteins)* in Vopr. biofiz. (Problems of biophysics), translated from English, edited by G.M. Fink, p. 205, Moscow, 1957.

Kol'man, E., *Chto takoye kibernetika (What is cybernetics?)*, Vopr. filosofii, No. 4, p. 148, 1955.

Kossa, P., *Kibernetika (Cybernetics)* translated from French, Moscow, 1958.

Poletayev, I.A., *Signal (on certain concepts of cybernetics)*, Moscow, 1958.

Problemy kibernetiki (Problems of cybernetics), edited by A A. Lyapunov, No. 1, Moscow, 1958.

Sobolev, S.L., Kitov, A.I., and Lyapunov, A.A., *Osnovnyye cherty kibernetiki (Fundamental outlines of cybernetics)*, Vopr, filosofii. No. 136, 1955.

Trakhtenbrot, B.A., *Algoritmy i mashinnoye resheniye zadach (Algorithms and machine solution of problems)*, Moscow, 1957.

Chlenov, L.G., *Kibernetika i nevrologiya (Cybernetics and neurology)*, Zhurn. nevropat. i psikhiat. (J. neuropathology and psychiatry), Vol. 58 , No. 10, p. 1259, 1958.

Ashby, W., *Vvedeniye v kibernetiku (Introduction to cybernetics)*, translated from English, Moscow, 1959, and *Primeneniye kibernetiki v biologii i sotsiologiy (Applications of cybernetics in biology and sociology)*, vopr. filosofii, No. 12, p. 110, 1958.

Yaglom, A.M. and Yaglom, I.M., *Veroyatnost' i informatsiya (Probability and information)*, Moscow, 1957.

Bush, R.R. and Mosteller, F., *Stochaistie models for learning*, New York/London, 1955.

Congres International de cybernetique, Namur, 1956, Actes P., 1958.

Gamow, G., *Information transfer in the living cell*, Sci. Amer., Vol. 193, No. 4, p. 70, 1955.

Information theory in biology, ed. by E. Quastler, Urbana, 1953.

Rodriguez, H., *Psicologia y cibernetica*, Buenos Aires, 1958.

Walter, W.G., *An imitation of life*, Sci. Amer., p. 42, May, 1950 and *The living brain*, N.Y., 1953.